Discontinuities in the IGS tracking stations coordinate time series

Mendes Cerveira Paulo Jorge, Weber Robert
Vienna University of Technology, Institute of Geodesy and Geophysics
Advanced Geodesy, 128/1
Gusshausstrasse 27-29, A-1040 Vienna

Abstract

Height coordinate time series were recovered from the weekly SINEX solutions of the CODE (Center for Orbit Determination in Europe) Analysis Center and from the weekly SINEX files of the IGS combination, which are based on coordinate solutions of up to eight IGS Analysis Centers (ACs). These coordinate series cover a 4.5 years period ranging from August 1999 till February 2004. First of all, remaining discontinuities in the height data were removed. This is an indispensable condition for further investigations. Later on, we estimated from the time series a linear trend as well as the amplitudes of annual and semiannual variations per station. Considerable differences, especially in the annual amplitudes, can be detected between the IGS combined and the CODE time series. The CODE series show larger amplitudes due to a special modeling of the tropospheric delay or more probable, due to a periodical behavior of the scale and z-shift parameters aligning the CODE solution to IGS00. In general, sometimes the limited accuracy of the alignment parameters between AC-solutions and the IGS00 affects the combined IGS solution considerably.

Background

Temporally varying oceanic, atmospheric and continental water mass surface loads cause the Earth's gravitational field, local stress fields, topography and center-of-mass of the solid Earth to change. It affects both observing stations and satellite orbits. Moreover, tidal and non-tidal processes play an important role in Earth rotation dynamics and terrestrial reference system realization, whose maintenance is periodically subject to changes and modifications. The present work represents an attempt to characterize IGS station coordinate time series under various aspects in order to finally gain insight into surface loading processes on the Earth. Unfortunately, coordinate time series contain numerous non-stationary or transitory characteristics: linear trend, nonlinear drift, beginnings and ends of events, discontinuities, and self-similarity characteristics (e.g. because of earthquakes or antenna height changes). One aim for the detection of discontinuities and abnormal behaviour is to separate geophysical signal from systematic errors. Identifiable discontinuities that occur at a specified time or cause an abrupt but continuing transition can be distinguished with special algorithms. But sometimes, seasonal variations have the appearance of a discontinuity. Furthermore, small real jumps actually approach the processing noise level. Generally, the smaller the anomaly, the longer a time series is required to identify it with a high degree of confidence. A tuned decision threshold is recommended.

Data

As may be anticipated from Figure 1, we downloaded the SINEX 'ssc' and 'sum'-files from the ftp://cddisa.gsfc.nasa.gov/pub/gps/products/ server. This has been done for each available analysis center from GPS week 1020 till week 1252. The coordinates (for the IGS weekly coordinates and for each AC) from the weeks 1021 to 1142 have been transformed from ITRF97 to ITRF00 (IGS00) by the available similarity transformation (ACCm_III_01.txt). Moreover, from the Wk IGS SINEX COMBINATION report files, we implemented the 7-parameter transformation (only for ACs) accounting for the ACs transformation to the 54 quasi-fixed IGS stations. Cartesian coordinates have been transformed to ellipsoidal coordinates (BLH) and to local level coordinates (NEU). Only the radial (vertical) component has been studied herein. In this paper, we mainly deal with the weekly SINEX coordinate time series solutions of the CODE Analysis Centre and the IGS combination. Only stations providing more than 156 GPS weeks data over the mentioned interval have been considered.
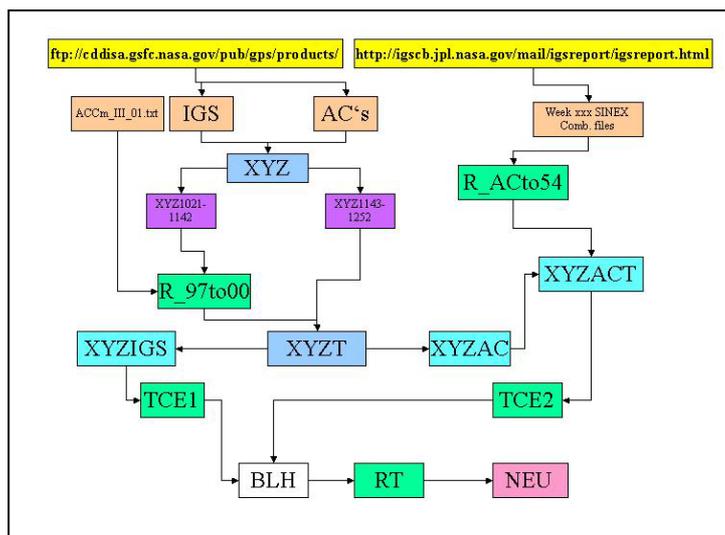
Figure 1. Time series pre-processing.

Methods

Superimposed transient characteristics are an important part of the signal. Therefore, we performed FFT spectral analyses, outlier and discontinuities detection, and wavelet transformations. Fourier analysis is not suited to detect abrupt changes in the time series. Wavelet analysis, using a time-scale region, allows the use of long time intervals where precise low-frequency information is needed, and shorter regions where we want high-frequency information. The dyadic form of the DHWT (Discrete Haar Wavelet Transform) has been applied to the mean-centered raw data, i.e. subsequent differences in x, y and z-components in IGS00, after the data was pre-filtered by the FMH (Finite Median Hybrid) filter. Figure 2 shows the outrageous result of the employed algorithms for the IGS station Fairbanks. The efficiency of these algorithms has only been proven for time series with few missing data points. The large discontinuity at epoch 2002.8, visible in Figure 2, was due to a strong earthquake that occurred in central Alaska.
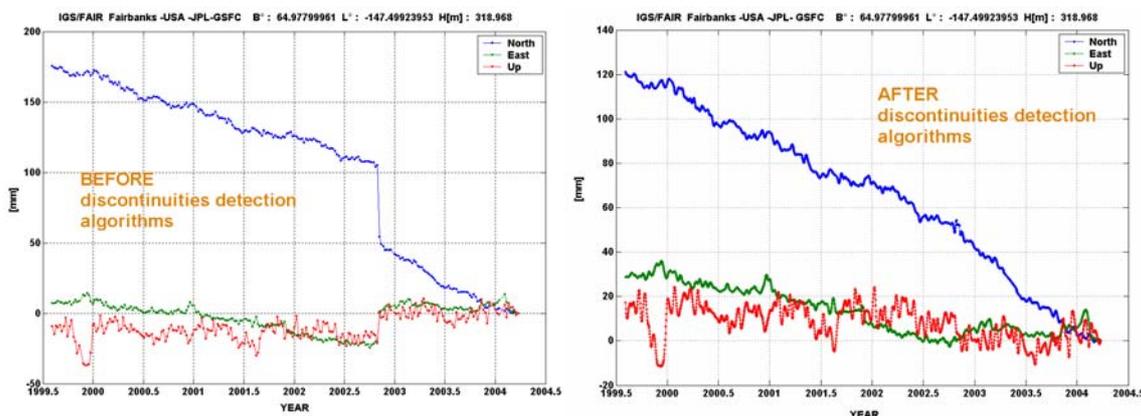
Figure 2. Result of the discontinuities detection algorithms for IGS station Fairbanks, USA.

To achieve reliable results in further studies of the time series, this rigorous data cleaning carried out by the above-mentioned methods, is an absolute must.

Results

Geostatistical calculations by means of ordinary Kriging have been performed for graphical representation. Sharp changes of annual amplitudes at IGS sites afford an elaborate semi-variogram exponential-cosine function, accounting for sill, nugget, length and range. The 2-D correlogram map provides information on anisotropy. The angle (in degree) is measured counterclockwise with respect to the horizontal axes (e.g. Figure 3).

Semi-Variogram & Correlogram: IGS annual amplitudes
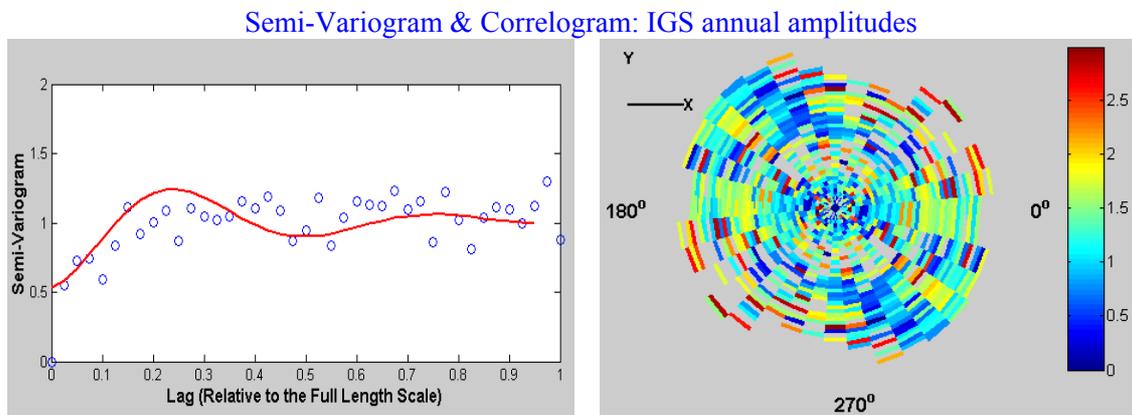
Figure 3. 1D Semi-Variogram & 2D Correlogram of IGS annual amplitudes data.

The estimated annual amplitudes in the vertical component time series are twice as large for the CODE Analysis Center than for the final weekly IGS solution (e.g. Figure 4). Inappropriate tropospheric mapping functions or probably a periodical variation of the scale parameter aligning the CODE solution to IGS00 could explain this phenomenon. Further investigations are necessary to spot how this periodically varying scale comes about. As there is a mathematical correlation between scale and z-shift, the latter also exhibits the same periodical behaviour, and can't therefore be separated properly from the scale effect.
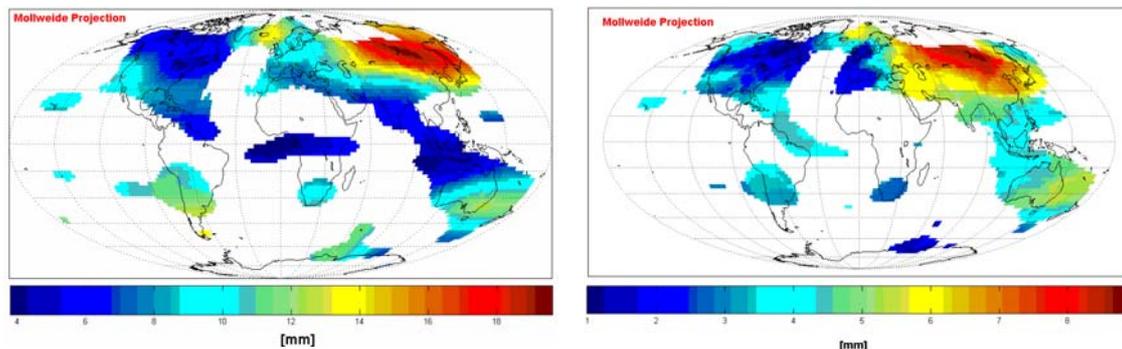
Figure 4. CODE (left) and IGS (right) vertical component annual amplitudes.

The most important vertical annual amplitudes (~9 mm) of the IGS time series are situated over the Asian continent. Recent studies on atmospheric loading models showed a similar pattern over the same region of Asia.

Inaccurate transformation parameters, to align the ACs solution to IGS00, can also affect the IGS weekly combination solution (e.g. Figure 5). An STD of 0.25 parts per billion in the scale corresponds roughly to an uncertainty of nearly 2 mm in the radial component of a station on the Earth's surface. Uncertainties in the transformation parameters unfortunately propagate directly into the precision and to some extent into the accuracy of the IGS weekly coordinate time series.
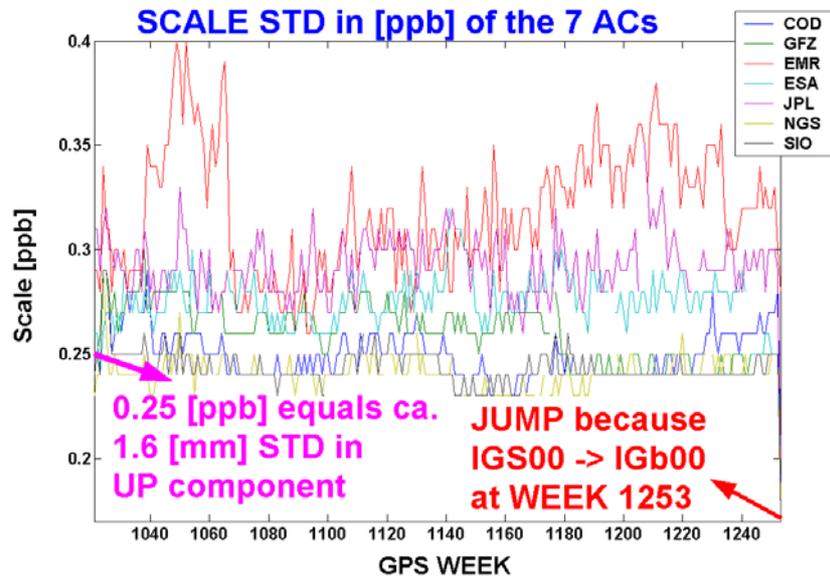
Figure 5. Scale standard deviation estimates for the 7 ACs.

Finally, our time series model for the vertical component, containing an offset, linear trend, annual and semi-annual term, is very reliable for nearly 75% (~100) of the analysed IGS stations. Residuals follow a normal distribution with an STD of ~4.5 [mm].
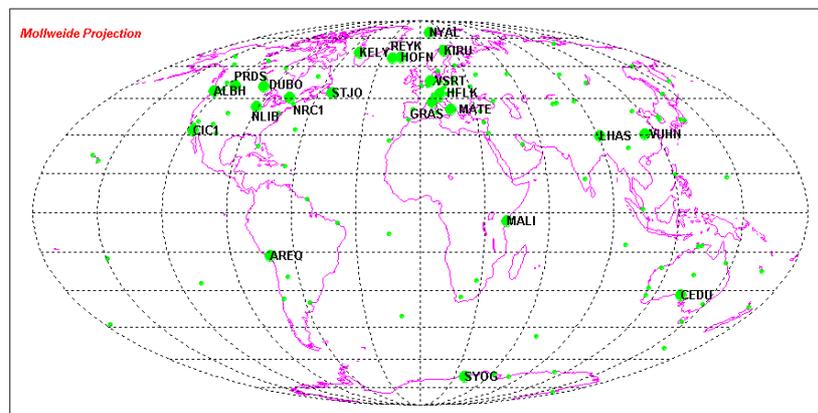
Figure 6. 22 IGS stations with non-normal distributed residual variations.

For the remaining 25% (e.g. Figure 6) of IGS stations, the model is either not appropriate or these stations simply flicker abnormally. Disturbances of GPS measurements could be at the origin of this strong flicker.

Especially sensitive to discontinuities in the coordinate time series, is the estimation of reliable horizontal and vertical coordinate trends. Therefore, further improvements in the discontinuities detection techniques are absolutely primordial.

References

Bos, M.S., Baker T.F., 2000. Ocean tides and loading in the Nordic Seas. Memoirs of National Institute of Polar Research (Japan), Special Issue, No.54.

Crétaux, J-F., Soudarin, L., Cazenave, A., and Bouille, F., 1998. Present-day tectonic plate motions and crustal deformations from the DORIS space system, Journal of Geophysical Research, Vol.103, pp.30167-30181.

Dong, D., P. Fang, Y. Bock, M. K. Cheng, and S. Miyazaki, 2002. Anatomy of apparent seasonal variations from GPS derived site position time series, Journal of Geophysical Research, VOL.107, 10.1029/2001JB000573.

Eanes R.J., S.V. Bettadpur, 1999. The CSR 4.0 global ocean tide model.

Farrell, W.E., 1972. Deformation of the Earth by surface loads. Rev. Geophys. Space Phys., No.10, pp.761-797.

Hatanaka, Y., A. Sengoku, T. Sato, J . M Johnson, C. Rocken, and C. Meertens, 2001 Detection of tidal loading signals from GPS permanent array of GSI Japan, J. Geod. Soc. Jpn., Vol.47(1), pp.187-192.

Le Provost C., M. Genco, F. Lyard, P. Incent, P. Canceil, 1994. Spectroscopy of the world ocean tides from a finite element hydrological model. Journal of Geophysical Research, Vol.99, pp.24777-24798.

Mathews, P.M., V. Dehant, and J.M. Gipson, 1997. Tidal station displacements. Journal of Geophysical Research, Vol.102, pp.20469-20477.

McCarthy and Petit, 2003. IERS Conventions 2000. http://maia.usno.navy.mil/conv2000.html

Petrov, L., and C. Ma, 2003. Study of harmonic site position variations determined by very long baseline Interferometry. Journal of Geophysical Research, Vol.108(B4), 2190, doi:10.1029/2002JB001801.

Ray R.D., 1999. A Global Ocean Tide Model from TOPEX/POSEIDON Altimetry: GOT99.2. NASA/TM-1999-209478. National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, MD.

Rothacher M., G. Beutler, R. Weber, J. Hefty, 2000. High Frequency Earth Rotation Variations from three Years of Global Positioning. System Data. Submitted to the Journal of Geophysical Research.

Scherneck, H.G., Haas, H., and Laudati, A., 2000. Ocean Loading Tides For, In, and From VLBI. Proc. First IVS General Meeting, Kötzting, edited by N. Vandenberg and K. Baver, pp.257-262.

Schuh, H., Estermann, G., Crétaux, J.-F., Bergé-Nguyen, M., van Dam, T., 2003. Investigation of hydrological and atmospheric loading by space geodetic techniques. International workshop on satellite altimetry for geodesy, geophysics and oceanography. Wuhan, September 2002. IAG Symposia Series, Springer.

Schwiderski, E., 1983. Atlas of Ocean Tidal Charts and Maps Marine Geodesy, Vol.6, pp.219-256

van Dam, T.M., Plag, H.-P., Francis, O., and Gegout, P., 2002. GGFC Special Bureau for Loading: Current Status and Plans. IERS Workshop, Nov. 2002, Munich.

Weber R., 1999. The Ability of the GPS to Monitor Earth Rotation Variation in 'Acta Geodaetica et Geophysica Hungarica', Vol.34, Number 4, pp.457-473, Akademiai Kiado, Budapest.